URANIUM GEOLOGY AND PRODUCTION HISTORY OF THE SANOSTEE AREA, SAN JUAN COUNTY, NEW MEXICO

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by

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INTRODUCTION

Location

The Sanostee uranium mining area is located on the eastern flank of the Chuska Mountains in northwestern New Mexico. The principal mine, the Enos Johnson, is located approximately 7 mi west of the settlement of Sanostee, in San Juan County (Figure 1).

The area is of interest since the Enos Johnson mine is the only uranium mine in New Mexico, outside of the Grants mineral belt, which produced uranium ore in the 1970's and 1980's.

Orebodies at the mine are in a sandstone channel in the upper portion of the Recapture Member of the Morrison Formation of Jurassic age. In the Sanostee area, uranium ore has also been produced from the lower portion of the Recapture Member, the Salt Wash Member of the Morrison Formation, and from the Todilto Limestone. During the period 1952 through 1982, a total of 138,200 tons of ore containing 333,700 pounds of uranium oxide (U_3O_8), and averaging 0.12% U3O8 have been produced from 16 properties. Nearly 98% of their uranium came from the large underground mine on Enos Johnson's mining permit.

The area is on the Navajo Indian Reservation, and all prospecting and mining is regulated by the Navajo Tribal Council and the Bureau of Indian Affairs.

Previous Work

The work of the Atomic Energy Commission (AEC) in the Sanostee area has been summarized by Blagbrough and others (1959). Hilpert (1969) in his compilation on uranium data in northwestern New Mexico, largely relied on Blagbrough's work, although it was not yet open filed.

A report by Anderson (1981) describes the condition of the abandoned mines. Data from Blagbrough and others (1959), and Hilpert (1969) was summarized in a compilation by McLemore (1982). The Enos Johnson mine was examined by geologists of the U.S. Geological Survey (USGS) during the National Uranium Resource Evaluation program (Green and others, 1982).

Scope and Purpose

This report is the result of the authors visits to the Sanostee area during the 31 years he was associated with the AEC and succeeding agencies: the Energy Research and Development Administration and the Department of Energy. The production statistics are based on data compiled when the author routinely supplied annual uranium production data to the New Mexico Bureau of Mines and Mineral Resources. Two previous reports (Hilpert, 1969 and McLemore 1982) confused the H. B. Roy No. 2 property in the Todilto Limestone with the No. 1 property in the Recapture Member of the Morrison Formation, and didn't realize that the Todilto produced ore which the AEC purchased.

Acknowledgements

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GEOLOGY

The Sanostee uranium mining area is approximately 7 mi west of the settlement of Sanostee in the headwater of Sanostee Wash (Fig. 2). The area has been referred to as the Chuska mining district in early AEC reports. A few uranium prospects are located in Bear Creek Canyon, northwest of the area shown in Figure 2. Bear Creek flows northward and joins Red Wash approximately 3 1/2 mi south of Red Rock Trading Post (Fig. 1).

The area of the mines is located on the Defiance monocline, a north-northwest trending, east-northeast dipping structure separating the Defiance uplift from the Four Corners platform of the San Juan Basin.

Sedimentary rocks exposed in the area range from the Chinle Formation of Triassic age to the Crevasse Canyon Formation of Cretaceous age. These rocks dip from 5 to 15 degrees to the east-northeast. In general, the dip is steeper near the Chuska Mountains and decreases eastward. The dipping Mesozoic rocks are unconformally overlain the nearly horizontal Chuska Sandstone of Pliocene (?) age.

Only the uranium-bearing units: Todilto Limestone, Salt Wash and Recapture Member of the Morrison Formation, will be described here, and their descriptions are largely taken from Blagbrough and others (1959).

Todilto Limestone

The Todilto is an impure dense gray very fine-grained thin-bedded limestone. The limestone is transitional downward into the Entrada Sandstone and upward into the Summerville Formation. In the Sanostee area Blagbrough and others (1959, p. 13) divided the Todilto into two lithologic units. The lower unit is composed of flat-lying slabby beds of less than 1 ft in thickness; the beds of the upper unit are somewhat thicker, ranging from 1 to 2 f t. The upper unit contains countless small folds with some coarsely recrystallized calcite. Nearly all the uranium reported in the Todilto is associated with the folds. A 6-inch bed of oolitic limestone occurs at some places at the top of the Todilto, and uranium minerals also have been observed in it.

The limestone caps mesas in the rugged canyonlands between the Chuska Mountains and the Morrison escarpment. It is also exposed in Bear Creek Canyon. The Todilto ranges in thickness from 6 1/2 ft in the northern part of the Sanostee area to 10 ft in the southern part.

Salt Wash Member, Morrison Formation

The Salt Wash, the basal member of the Morrison Formation, is an alternating sequence of green and red mudstones and siltstones and light gray and red sandstones. Mudstones and siltstones make up 60 to 75 % of the Salt Wash in the Sanostee area; commonly they grade laterally into sandstones. Sandstones are medium to very fine-grained, poorly sorted, and moderately cemented. Very fine-grained sandstones predominate. Some arenaceous beds contain carbonaceous trash and logs; all have fluvial festoon bedding and current lineation. A study of sedimentary structure indicates that the direction of paleostream flow on the Enos Johnson mining permit was chiefly to the southeast (Blagbrough and others, 1959, p. 13).

The Salt Wash commonly forms a slope between the resistant Bluff Sandstone below and the Recapture Member above. Contact between the Salt Wash and Recapture is generally distinct, the Recapture being the coarser-grained. In some places sandstones of the Recapture fill paleostream channels cut into the Salt Wash. One or two ft of reworked Bluff is usually found at the at the base of the Salt Wash.

The Salt Wash has an average thickness of about 50 ft in the Sanostee area. It thins to the south and is not present south of Toadlena, New Mexico (Fig. 1). The member thickens northward and is 75 ft in Bear Creek Canyon and 125 ft thick near Red Rock Trading Post (Fig. 1). The percentage of mudstone in the Salt Wash decreases from south to north. The flood-plain facies of mudstone and minor sandstone is exposed in the Sanostee Wash

area. Thick, continuous sandstone with minor mudstone is characteristic of exposures around Red Rock. An intermediate zone of interbedded lenticular mudstone and sandstone is exposed in Bear Creek Canyon.

Recapture Member, Morrison Formation

The Recapture is approximately 475 ft thick in the Sanostee Wash area and is about 500 ft thick in Bear Creek Canyon. AEC geologists divided the member into an upper and a lower lithologic unit. The lower Recapture, about 275 ft thick, is exposed as a series of three predominantly red sandstone cliffs separated by benches. Fine-grained eolian sandstones compose a large proportion of the lower unit. Interbedded with the eolian deposits are fine- to coarse- grained fluvial deposits with minor interbedded red siltstone and mudstone. Measurements by the USGS on the channel deposits indicate a braided stream system generally flowing to the north- northeast. Measurements on the eolian dunes indicate a wind direction to the east-southeast (Green and others, 1982, p. 16). Carbonzied fossil logs occur in the lower beds. The contact between the upper and lower units of the Recapture is gradational and based largely on degree of friability.

The upper unit of the Recapture is a series of friable light -red to light-gray fluvial sandstones and is about 200 feet thick in the Sanostee Wash area. Due to the friable nature of the upper Recapture it usually forms a gentle rounded slope, bearing a mantle of soil, between the more resistant lower Recapture and

the overlying Westwater Canyon Member of the Morrison Formation. The upper unit consists of coarse- to very fine-grained predominantly red with some light-gray sandstones and minor amounts of interbedded red and green mudstones. The sandstone units have festoon and planar bedding and grade laterally into mudstones and siltstones. Transport directions were to the north-northwest and most of the streams were braided, although there are indications of meandering streams (Green and others, 1982 p.16) Contact between the Recapture and Westwater Canyon is sharp, as the Westwater Canyon forms a cliff above the Recapture and is a medium- to coarse-grained yellow-brown sandstone.

In the area of the Enos Johnson mining permit a conspicuous zone of light-gray sandstone ranging in thickness from 50 to 150 ft occurs in the upper Recapture 10 to 40 ft below its contact with the overlying Westwater Canyon. The thickness of this zone decreases both north and south of the Enos Johnson permit, and it is not recognizable northwest of the Deneh Nezz permit or south of the Carl Yazzie permit. At both of these localities light-red sandstone interfingers with light-gray sandstone. This bleaching of the sandstone is believed to be associated with passage of uranium-bearing solution through the sandstone.

The selenium indicator plant, Astragalus patteponi, grows profusely on the bleached zone and is especially evident in the spring when its white flowers are in bloom.

URANIUM DEPOSITS

Four stratigraphic units of Jurassic age contain uranium minerals in the Sanostee area: the Todilto Limestone, and the Salt Wash, lower Recapture, and upper Recapture Members of the Morrison Formation.

Todilto Limestone

Shipments of uranium ore have been made from the H.B. Roy No. 2 and the Reed Henderson properties in the southern part of the area (Fig. 2). Since the grade of the material from the Reed Henderson prospect averaged less than 0.10% U_3O_8, the minimum the AEC accepted, no payment was made for this material.

AEC reconnaissance found that yellow minerals occur sparsely in the upper 5 ft of the Todilto Limestone at several localities from the Reed Henderson property northward to the Tyler prospect (Fig. 2). No uranium is known in the Todilto Limestone in its outcrops in Bear Creek Canyon.

The AEC identified tyuyamunite and metatyuyamunite in Todiltic samples from Sanostee, and Gruner and Knox (1955, p.36) identified cuprosklodowskite in samples from the Reed Henderson prospect.

The uranium minerals occur chiefly on joint planes and as lining of vugs in areas of recrystallized calcite, especially on the flanks of anticlinal folds. Chlorite, hematite, and manganite are commonly associated with the mineralized folds. The small anticlinal folds have a width of about 3 ft, a height of 1 or 2 ft, and a length of 10 or 15 ft. Between anticlines beds are flat rather than bowed downward. In areas of intense

folding the fold axes are from 5 to 20 ft apart. The axes frequently have a common orientation in areas of intense folding, but they do not appear to parallel any of the Laramide structures. The folds are not reflected in the lower portion of Todilto nor in the Summerville Formation above. The areas of most intense folding are those most highly mineralized. Coarse-textured calcite is commonly found in the folds. Since the folds are confined to the upper part of the Todilto Limestone and not reflected in older Todilto or in younger rocks, they are presumed to be diagenetic, as also is the coarsely crystallized calcite associated with them.

The Sanostee area is one of two areas, outside the Grants mineral belt, in the San Juan Basin which has produced uranium from the Todilto Limestone, the other being the Box Canyon claim near Coyote, in Rio Arriba County (Chenoueth, 1974).

Salt Wash Member, Morrison Formation

Uranium in the Salt Wash has been mined from the Carl Yazzie No. 1, Enos Johnson Nos. 1 and 2, Joe Ben No.3 and the John Joe No. 1 projection (Fig. 2). Oxidized vanadium minerals, including uranium vanadates, have been located in the Salt Wash as far north as the John Joe No. 2 property (Fig. 2). No uranium in the Salt Wash has been reported south of the Carl Yazzie No. 1 Mine, or in Bear Creek Canyon to the north. The minerals occur in light-to medium-gray sandstone in the upper part of the Salt Wash. The lower portion, which contains a large percentage of siltstone and mudstone, does not contain uranium.

The deposits in the Salt Wash are small, approximately 150 tons, and have an average grade of about 0.15 % U_3O_8, 0.70 % V_2O_5, and 15 % $CaCO_3$. The deposits have a diameter of 25 to 50 ft and are oval in shape with an average thickness of 1 1/2 ft.

Uranium is disseminated in the sandstone as grain coatings and as cement. Blagbrough and others (1959, p. 17) recognized three types of deposits in the Salt Wash. In one, the minerals are directly above or below a mudstone, in very fine-grained light-gray sandstone. The mudstone in the vicinity of uranium is altered from normal red to green. The mineralized zone is thin and tabular and parallels the mudstone for 25 to 50 ft. It ranges in thickness from a few inches to 2 ft. At places the sandstone fills a scour in the mudstone, and uranium is concentrated in the scour.

A second type of deposit is in a light-gray very fine-grained sandstone lens rich in carbonaceous trash. The uranium occurs in carbon trash and at places forms a halo around it. The

mineralized area ranges from a few inches to 2 feet in thickness and from 25 to 50 ft in diameter. Limonite is commonly associated with the carbon-trash type of deposit.

A halo of uranium around a carbonized log constitutes the third type of deposit. The logs have diameters of 1 to 2 ft and commonly are 3 or 4 ft long. Uranium fills fractures in the log and is also disseminated in the very fine-grained light-gray sandstone around it.

The Salt Wash ores from throughout the Colorado Plateau are well known for their high vanadium content. Ores shipped from the nearby Lukachuhai and Carrizo Mountains (Fig. 1) had uranium to vanadium ratios of 1:4 and 1:9 respectively. With the exception of the Carl Yazzie No. 1 Mine in the southern part of the area, where the uranium to vanadium ration is 1:5, the Salt Wash ores from the Sanostee area were quite low in vanadium.

A mixing of the early production records from the Enos Johnson property could possible account for the low ratios in the reported production from the Salt Wash mines on the property. The uranium to vanadium ratios for the Enos Johnson Nos. 1 and 2 are 1:1.3 and 1:1 respectively. However, there should be no confusion on the adjacent Joe Ben No. 3 and John Joe No. 1 Mines where the ratios are 1:3.6 and 1:3 respectively.

Lower Recapture Member, Morrison Formation

Uranium ore has been shipped from deposits in the lower Recapture from the Deneh Nezz prospects and from the Joe Ben No. 1 prospect on the north side of Sanostee Wash (Fig. 2). These deposits area associated with mineralized fossil logs which occur

in the Recapture from 30 to 70 ft above the contact with the underlying Salt Wash Member. Mineralized logs have also been found on the David Kee property (Fig. 2), and on the White Cone property which is located on the west side of Bear Creek Canyon, in Apache County, Arizona. The logs are partly calcified, have a diameter of 2 to 3 ft and are 5 to 15 ft long. Uranium is in fractures in the logs and is also disseminated through a few feet of the enclosing sandstone. Adjacent to the logs, fine-grained sandstone is altered from red to light-gray. Mineralized areas have diameters as much as 4 ft.

The deposits in the lower Recapture have a maximum diameter of 20 feet and a thickness of 1 or 2 ft and contain between 5 and 10 tons of material averaging 0.30 % U3O8 and 0.30 % V2O5. The lime content is high, because the uranium is closely associated with calcified logs.

Upper Recapture Member, Morrison Formation

The upper Recapture contains the largest uranium deposits in the Sanostee area. Ore has been shipped from the Horace Ben and Enos Johnson properties on the south side of Sanostee Wash and the Castle Tsosie, and Kee and Tohe properties on the north side (Fig. 2). The Enos Johnson No. 3 Mine is largest and highest grade
deposit. Uranium in the upper Recapture occur from east of the Carl Yazzie Mine in the southern part of the area to the H.B. Roy No. 1 property in Bear Creek Canyon to the north.

The majority of the uranium in the upper Recapture is confined to a zone of light-gray sandstone with a maximum

thickness of 60 ft which occurs from 10 to 170 ft below the Recapture-Westwater Canyon contact. Mineralized zones range from 20 to 300 ft in length and from a few inches to 20 ft in thickness.

Blagrough and others (1959, p. 18) described two types of uranium occurrances in the upper Recapture. In the first, uranium occurs above or below a mudstone or siltstone unit, in a medium- to fine-grained light-gray sandstone. The siltstone or mudstone is commonly 2 or 3 ft thick and is altered from red to green. The mineralized zone is a few inches to 2 ft thick and ranges in grade from a trace to as much as 1 % U_3O_8. Uranium is for the most part fairly continuous along the siltstone or mudstone unit, and some uraniferous zones can be followed for a distance of 300 ft. The richest deposits occur along mudstones which lie unconformably on sandstones; deposits along siltstones are commonly low in grade.

The second type of mineralized zone ranges in thickness from a few inches to 20 ft and has a lateral extent of as much as 300 ft. The uranium is in a medium- to fine-grained light-gray thick sandstone lens as a halo around lime concretions that range in diameter from a few inches to 6 ft. Thin, irregular stringers and pebbles of mudstone and siltstone also have halos of uranium which are as much as 3 ft thick. The mudstones are chiefly red, but siltstones are altered to green. Uranium is also found in sandstone lenses containing red mudstone galls. Where it forms a halo around and impregnates the lenses, it is commonly 1 or 2 ft thick. A thick mudstone or siltstone usually underlies the mineralized sandstones, and the lens is capped with an altered

mudstone or siltstone.

The AEC identified carnotite in samples collected from outcrops on the Enos Johnson property. Schroeckingenite was reported by Drollard and Jones (1951), and Gruner and Knox (1955, p.36) reported uranophane. Other than carnotite, no vanadium minerals have been identified, but some samples contain a higher ratio of vanadium to uranium than is present in carnotite, so that the presence of other vanadium-bearing minerals is indicated. Hematite, chlorite, and limonite are commonly associated with the higher grade deposits, and these minerals in some places mask the color of the carnotite. Chlorite is an ingredient of siltstone in the low-grade deposits. Chlorite, hematite, limonite, and carnotite coat and cement the sand grains.

The Enos Johnson No. 3 Mine - This mine has produced more uranium than any other mine in the Sanostee area. It is also known as the South Peak Mine and the Sanostee Mine. Beginning in 1958 the "No. 3" was dropped from the name as it was the only operating mine on Enos Johnson's mining permit. The portals of the mine are at an elevation of about 7,370 ft on the west side of a prominent mesa known as South Peak (Fig. 2).

When the mine closed in late 1982, the workings had extended some 2,800 ft in a east - northeast direction from the portals. Since the orebodies generally were parallel to the bedding of the host rock, the working are declined about 12 degrees to the east. The average width of the mined area is about 300 ft. Mining was by modified room and pillar methods. Ore was removed from the

mine by small diesel powered trucks. Radon gas was a problem at the mine, and the declined workings added to the ventilation problems. Radon, being heavier than air, would tend to accumulate in the deeper parts of the mine when the mining was proceeding.

The sandstone bed containing the Enos Johnson orebodies appears to be much more laterally continuous than other Recapture sands. The ore deposit is a series of orebodies separated by mineralized rocks which occur throughout a 20 ft thick zone in the host sandstone. A typical orebody will have length of 500 to 600 ft and a width between 150 and 200 ft. Ore thicknesses range from 1 ft to about 20 ft of discontinuous mineralization.

Ore grades are recorded in monthly ore receipts to the AEC and ranged from high of 0.25% U_{3O8} in the 1950's to 0.06% in the late 1970's with the average for the mine being 0.12% U308.

The vanadium content of the Enos Johnson No. 3 ores is quite low compared to ores from the Salt Wash Member. As already mentioned, the Salt Wash deposits at Sanostee also are lower than normal in vanadium. In this respect they resemble the deposits of the Grants district in New Mexico. The genesis of the Grants and Sanostee deposits may therefore have been significantly different from the genesis of other Morrison deposits of the Plateau.

The uranium to vanadium ratios in monthly ore receipts have ranged from 1:1.75 to 1:0.42 for the Enos Johnson No. 3 Mine. The ratio in 7,783 tons mined during 1952-56 was 1:0.89, in 2,399 tons mined during 1958-59 was 1:0.79, and in 8,950 tons mined in 1960-64 was 1:0.51. These statistics could possibly indicate a

decrease in vanadium as mining progressed downdip from the outcrop.

Very little is known about the mineralogy of the Enos Johnson No. 3 Mine. Samples of ore collected by the author in September 1961 from a reddish-brown siltstone were examined by the AEC's mineralogy-petrology lab. The lab (personal communication, 1962) found that uranium was disseminated in hematite coatings on quartz grains. The USGS (Green and others 1982, p. 17) reported coffinite in samples of dark black ore, and the association of uranium with hematite in reddish ores.

Analyses of several ore samples collected by the author indicated that chemical U_3O_8 exceeded the radiometric U_3O_8 by 25 to 30%. This would indicate that the uranium in the deposit is still migrating due to the lack of sufficient vanadium to fix it.

Summary

The higher grade uranium occurrances in the Todilto Limestone are found in small, intraformational folds in the upper part of the formation.

All uranium deposits in the Salt Wash at Sanostee are either closely associated with carbon or are directly above or below a green mudstone. The host rock is a light- to medium-gray sandstone rather than a red sandstone. Zones of light-colored sandstone associated with green mudstones or carbon are considered favorable.

Uranium in the lower Racapture is associated with fossil logs, and the sandstone in the vicinity of these logs is altered from red to a light-gray color. The sandstone alteration

associated with fossil logs is a guide to the small deposits.

Ore in the upper Recapture occurs in light-gray sandstones which are part of an altered zone 50 to 150 ft thick. Mudstones and siltstones that have an appreciable lateral extent and are closely associated with ore are altered from red to green.

The chief ore controls in the upper Recapture appear to be lateral and horizontal variations in permeability and presents of chemical reductants, such as fragments of organic carbon. Ore commonly occurs directly above a siltstone or mudstone in a medium- to fine-grained sandstone or in thick, medium- to fine-grained sandstone units which contain small stringers and pebbles of mudstone and siltstone, mudstone galls, and concretions of calcium carbonate. Zones showing these features are considered favorable for the occurrence of ore. Ore is also found in medium- to fine-grained sandstone lenses in channels of paleostreams.

The altered zone in the upper Recapture is marked on the outcrop by the occurrance of the selenium indicator plant, Astragalus patteroni.

PRODUCTION HISTORY

Summary of the AEC Program

During the period 1947-1970, the AEC purchased uranium concentrate from private companies primarily for use in military weapons programs. Prior to April 1, 1962, the AEC also purchased uranium ores and guaranteed the prices to be paid by the milling companies for ores as an incentive to the uranium mining industry to provide feed for the processing mills. The prices the AEC paid for uranium concentrate were negotiated independently with each milling company.

In the beginning of the AEC program, ore producers were paid for their ores under the terms of the AEC's Circular 5, Revised. This schedule contained a base price of $3.50 per pound U_3O_8 for ores containing 0.20% U_3O_8 or greater uranium oxide. Ores containing less than 0.20% U_3O_8 received a base price grading down to $1.50 per pound U_3O_8 in ores containing the minimun acceptable grade of 0.10% U_3O_8. All ores received a mine development allowance of $0.50 per pound, and ores containing 0.21% U_3O_8 and better received a $0.75 per pound grade premium. Vanadium-bearing ores received $0.31 per pound V_2O_5 for their vanadium content. The AEC also paid $0.06 per ton-mile haulage allowance for the first 100 miles.

On May 24, 1956, the AEC announced the establishment of a new domestic uranium procurement program for the period April 1, 1962, through December 31, 1966. The new program guaranteed a Government market for 500 tons of U_3O_8 in concentrate per year from any one mining property or operation at a flat price of $8 per pound. Thus, in 1956, the stage was set for a continuing AEC

concentrate procurement program after March 31, 1962, with an established price for concentrates rather than for ores. The prices, premiums, and allowance paid under Circular 5, Revised, would no longer be in effect. After March 31, 1962, the AEC required that the mill operator pay "reasonable" prices.

By late 1957, dramatic increases in reported ore reserves and in milling capacity prompted an AEC announcement that "it no longer is in the interest of the Government to expand production of uranium concentrate." Then, in November 1958, in order to prevent further expansion of production under its essentially unlimited purchase commitment, the AEC redefined its 1962-1966 procurement program by withdrawing portions of the program announced in May 1956. The Government stated it would buy, in the 1962-1966 period only "appropriate quantities of concentrate derived from ore reserves developed prior to November 24, 1958, in reliance upon the May 24, 1956, announcement." Other aspects of the program announced in 1956 were retained: The AEC would buy only concentrates; the U_3O_8 price would remain at $8 per pound; and ores would not be purchased nor ore prices guaranteed. Independent producers had to negotiate ore purchase contracts with milling companies in order to sell their ores.

With the objective of fostering the development and utilization of atomic energy for peaceful purposes, the AEC announced on May 8, 1958 that "domestic producers of uranium ores and concentrate may now make private sales of these materials to domestic and foreign buyers for peaceful uses of atomic energy." All such sales would be subject to licensing by the AEC, and the release of uranium under contract to the AEC would be considered,

suject to appropriate contract modifications. While this announcement removed the legal impediment to private sales of uranium concentrate, no such sales were actually made until 1966.

In 1962, it was apparent to the AEC that the private market for uranium concentrates would not be sufficient to sustain a viable domestic uranium industry by the end of 1966 when the AEC procurement program was scheduled to end. Thus, on November 20, 1962, the AEC announced its "stretch-out" program for 1967 through 1970. Under the program, the milling companies could voluntarily defer delivery of a portion of their 1963-1966 contract commitments until 1967 and 1968 in return for an AEC commitment to purchase, in 1969 and 1970, an additional amount of U_3O_8 equal to the quantity so deferred. The "stretch-out" program was the last of the major policy changes made in the AEC procurement program.

The price to be paid for the deferred material in 1967 and 1968 would be $8.00 per pound, the same as the 1962-1966 contracts. The price to be paid in 1969 and 1970 for concentrate produced from properties controlled by the milling company would be calculated with a formula based on costs during the 1963-1968 period, not to exceed $6.70 per pound. The price for all concentrates produced from ores purchased from independent producers would be $6.70 per pound of contained U_3O_8. The AEC program ended at midnight, December 31, 1970.

AEC Activities and Early Production

Uranium mineralization west of Sanostee Day School, San Juan County, New Mexico was brought to the attention of U.S. Atomic

Energy Commission (AEC) geologists in early 1951, by M.W. Watters of Dolores, Colorado. Philip C. Ellsworth (1951) of the AEC made a preliminary reconnaissance of the area on May 2-3, 1951, and reported three areas of strong mineralization spaced about one mile apart in the upper Recapture Member of the Morrison Formation. A radiometric survey of the area was made by AEC geologists, and in June 1951 approximately 5,000 ft of outcrop was exposed by Commission bulldozing (Droullard and Jones, 1951).

After mapping and sampling the rim stripped area, Droullard and Jones (1951) estimated that a total of 426 tons averaging 0.352% U_3O_8 had been exposed in nine separate outcrops. They also recommended drilling behind the outcrops, and to test the underlying Salt Wash Member where uranium mineralization also had been located.

The initial discoveries, and subsequent rim stripping, was on ground informally claimed by Enos Johnson and Enos Johnson, Jr. of Sanostee. The area was approximately 7 mi west of Sanostee School on the north and west slopes of a mesa known as South Peak. The discoveries on the Enos Johnson property would trigger a great deal of prospecting in the Jurasic rocks exposed on the east flank of the Chuska Mountains in the Sanostee and adjacent areas.

On January 7, 1952, the AEC opened an ore buying station at Shiprock, New Mexico. The station, operated by the American Smelting and Refining Company (AS&R), provided a market for ores in northeastern Arizona and northwestern New Mexico, mostly from the Navajo Indian Reservation. In March of 1952, the Navajo

Tribal Council, with the approval of the Bureau of Indian Affairs, began issuing a new series of numbered mining permits to members of the Tribe. A permit could be assigned to non-Navajos to operate the property, with both the individual Navajo and the Tribe receiving royalties.

The initial shipment of uranium ore from the Sanostee Area was received at the Shiprock buying station on June 26, 1952 (AS&R, 1952, written communication). A 6 ton shipment averaging 0.36% U_3O_8 and 0.42% V_2O_5 was received from Joe, Jody B., and Robert G. Rogers, d.b.a. Rogers and Sons, who had the assignment of Joe Ben's Mining Permit No. 17. This shipment came from a small pod of mineralization in the lower Recapture Member of the Morrison Formation on the north side of Sanostee Wash (Fig. 2).

Tribal Mining Permit No. 18 was approved to Enos Johnson and Enos Johnson, Jr. on April 26, 1952. The permit covered an area to the east of them. The assignment of the permit to Roland D. Young was approved on August 6, 1952.

The initial shipment of ore from the Enos Johnson permit was received at the Shiprock buying station on July 15, 1952 (AS&R, 1952, written communication). It consisted of 18 tons which averaged 0.14% U_3O_8 and 0.23% V_2O_5. Enos Johnson, Sr. was listed as the shipper for the initial 980 tons of ore produced from the property. These shipments averaged 0.10% U_3O_8 and 0.15% V_2O_5, and according to notes in the AEC files, came from the original rim stripped area in the upper Recapture.

When Roland D. Young began shipments from the property on September 11, 1952, he continued to designate the rim stripped areas as the Enos Johnson property. Production from the Salt

Wash Member was designated Enos Johnson Nos. 1 and 2, and production from an underground mine in the upper Recapture was initially labeled as the Enos Johnson No. 3. This mine was also know as the South Peak Mine (Fig. 2, Table 1).

Young did about 2,500 ft of rim stripping in the upper Recapture on the north side of South Peak in 1952. Shipments from this area also would be designated Enos Johnson, without a number.

Other shipments received in 1952 included 4 tons averaging 0.17% U308 and 0.24% V205 from the Horace Ben property (MP-37) in the upper Recapture, operated by J.C. Cox and Glover Rogers southeast of the Enos Johnson mines, (Fig. 2), and 115 tons of "no pay ore" averaging 0.06% U_{308} and 0.20% V205 from the Deneh Nezz permit (MP-42) assigned to Rogers and Sons, covering mineralization in the lower Recapture on the north side of Sanostee Wash (Fig. 2). The spelling of this property has appeared in various forms--Dennet, Denneh, Denet, Nez, etc.--however, the form used in this report is the spelling as it appears on a copy of the Tribal Mining Permit in the AEC files.

Total production in 1952 was 1,743 tons of ore containing 4,278 pounds U_{308}, and averaging 0.12% U308 (Fig. 3).

An airborne radiometric survey of the outcrops of the Morrison Formation was began by the AEC in June 1953. The survey was abandoned in July due to turbulent atmospheric conditions. No significant anomalies were discovered (Siapno. 1953).

In the late summer, 1953, the AEC carried out a sampling program of the bleached zone in the upper Recapture on the Enos Johnson permit. This study was to determine if this zone

constituted a large, low-grade orebody. The results of the sampling indicated the zone averaged less 0.05% U_3O_8 (Blagbrough and others, 1959). In October 1953, the AEC had established a reconnaissance camp in the area, to study the deposits for possible ore guides and to plan drilling projects. Navajo Indians were employed, through the AEC's prime contractor Walker-Lybarger Construction Company, to prospect areas considered favorable. Rim stripping was done on several properties, including the Enos Johnson Nos. 1 and 2, the Joe Ben No. 3, and the John Joe properties in the Salt Wash.

During 1953, production continued to increase on the Enos Johnson permit. Other properties which made shipments during the year included 146 tons averaging 0.16% U_3O_8 and 0.73 V_2O_5 from the Joe Ben No. 3 mine in the Salt Wash, and 11 tons averaging 0.11% U_3O_8 and 0.36% V_2O_5 from the Deneh Nezz No. 1 in the lower Recapture (Fig. 2). Both shipments were made by Rogers and Sons.

In 1954 exploration by the various operators included rim stripping, wagon drilling and aerial radiometric surveys. In addition to production from the Enos Johnson ground, Bee-Shoshee Mining Company shipped 23 tons averaging 0.15% U_3O_8 and 0.76% V_2O_5 from the Carl Yazzie No. 1 property in the Salt Wash, and 47 tons averaging 0.10% U_3O_8 and 0.28% V_2O_5 from the Kee and Tohe property in the upper Recapture (Fig. 2).

Rogers and Sons shipped an additional 17 tons averaging 0.30% U_3O_8 and 0.76% V_2O_5 from the Deneh Nezz No. 1 prospect.

Two properties in the Todilto Limestone made shipments in 1954. Both are located in the extreme southern part of the area,

outside the area shown in Figure 2. The Reed Henderson property, operated by Hancock and Hutchison, shipped 24 tons averaging 0.03% U_3O_8 and 0.11% V_2O_5. Since the grade of the uranium was less than 0.10% U_3O_8, as required by the AEC, no payment was received for the material.

The H. B. Roy No. 2 property, operated by Bigler and Johnson, made a shipment of 6 tons averaging 0.10% U_3O_8 and 0.28% V_2O_5. Hilpert (1969, p. 51) described the H. B Roy No. 1, located in the upper Recapture in Bear Creek Canyon, as the H. B. Roy No. 2, and credited the production to the sandstone property. Anderson (1981) located a small open pit at the location shown on Blagbrough and others (1959, Fig. 5) map, and confirmed the AEC records that the shipment came from the Todilto.

In July 1954, the AEC began its first drilling project in the Sansostee area. Between July 9, 1954 and January 11, 1955, 33 core holes with a total footage of 17,732 ft were drilled. Of these holes, seven penetrated the Todilto Limestone, another 7 were drilled through the Salt Wash, and the remaining 19 were bottomed just below the mineralized zone in the upper Recapture. The holes drilled on this project had a prefix P.

A second project of non-core holes, began on March 29, 1955 and was completed on August 11, 1955. Forty-eight air rotary holes totalling 18,750 ft were drilled to test the mineralized zone in the upper Recapture. These holes had a prefix AA. Details of the drilling projects are given by Blagbrough and others (1959) and Collyer (1957). All of the drilling was on the Enos Johnson and Horace Ben properties.

Twenty-four of the holes drilled into the upper Recapture

penetrated uranium values exceeding 0.10% U_3O_8, another 11 holes were mineralized in the range of 0.05% to 0.10% U_{308}. The uranium located by the AEC drilling would assist in the exploration and development of the Enos Johnson No. 3 Mine in the years to come.

Production at the Enos Johnson property continued to decline in 1955. Shipments were made by Rogers and Sons from the Deneh Nezz Nos. 1, 2 and 3 in the lower Recapture, and from the Joe Ben No. 3 and John Joe No. 1 in the Salt Wash (Fig. 2).

Early in 1956, Bee-Shoshee Mining Company shipped 12 tons of ore averaging 0.25% U308 and 0.08% V205 from the Castle Tsosie property in the upper Recapture, in the northwestern part of the area (Fig. 2). This would represent the last ore shipment from the Sanostee area from a property other than Enos Johnson.

Roland Young abandoned the Enos Johnson No. 3 Mine early in 1956 after shipping 630 tons of ore averaging 0.18% U_{308} and 0.16% V205 before shutting the operation down in the summer of 1956.

Operated by Shiprock Industries, Inc., the Enos Johnson Mine (the designation No. 3 was not used by Shiprock) began producing in the summer of 1958, mining ore that had been discovered by long-hole drilling adjacent to the mine workings. After shipping 2,399 tons of ore that averaged 0.18% U_{308} and 0.14% V205, Shiprock Industries closed the mine in the spring of 1959. The assignment of their mining permit was cancelled on March 1, 1961.

Mining Permit No. 18 would next be assigned to A and B Mining Company (Ivor Adair and Tom Balsely) on April 20, 1961. Sampling, and prospecting with a jackhammer throughout the mine

workings located additional ore, which had been bypassed by previous operators, especially beneath the floor of the mine.

A and B began shipments to the Texas-Zinc Minerals mill at Mexican Hat, Utah early in 1961. The Kerr-McGee mill at Shiprock would not accept the Enos Johnson ore due to its low vanadium content.

When the writer examined the mine in September 1961, the workings had intercepted AEC drill hole AA-70 and were approaching holes P-2, P-3, and AA-3 (see Blagbrough and others, 1959, fig. 7).

On November 15, 1962, the original Mining Permit No. 18 was converted to Mining Permit No. 584, which would include only 69.5 acres. In late 1962, A and B would begin shipping the Union Carbide mill at Rifle, Colorado, where the low vanadium ore from Enos Johnson was blended with high vanadium ores from the northern Colorado Plateau area. A and B Mining Co. would continue production until spring 1964 using the previous AEC drilling to guide their exploration. Production under the AEC program reached an all-time high level in 1963, when the Enos Johnson mine produced 4,214 tons of ore averaging 0.23% U_3O_8 and 0.12% V_2O_5 and containing 19,550 pounds U_3O_8 (Fig. 3).

Ray L. Williams acquired the assignment of Mining Permit No. 584 in early 1964 and continued to ship ore to the Rifle mill and to the Uravan, Colorado mill, also operated by Union Carbide Corp. Williams continued to ship to Colorado until 1970 when he switched to the Atlas Minerals' mill at Moab, Utah.

The AEC procurement program terminated at midnight December 31, 1970. By that time the underground mine on the Enos Johnson

permit had produced 34,678 tons of ore averaging 0.19% U_3O_8 and 0.13% V_2O_5. A summary of uranium and vanadium production from the 16 properties in the Sanostee area, under the AEC program is given in Table 1.

Post AEC Market and Production

As the AEC program drew to a close, the milling companies began negotiating sales contracts with electric utilities for their uranium concentrate. Prices paid to independent mines were based on the sale prices of the mill in company's concentrate.

In the early 1970's the price of uranium oxide in concentrate was about $6.00 per pound. Prices began to rise in 1975 and reached $40.00 per pound in 1976. The spot market price remained in the low $40's until early 1980 when it began a sharp decline, reaching $17.00 per pound in late 1982. Because of long term contracting by the milling companies, the prices of uranium delivered in any one year are somewhat higher than the spot market prices for the same year.

The Enos Johnson mine continued to make shipments to Atlas Minerals at Moab, Utah until the summer of 1971, when the mine closed due to low uranium prices in the private market.

With uranium prices beginning to increase in the mid 1970's, Ray L. Williams reopened the Enos Johnson Mine in 1976. Large quantities of low grade material which had been stockpiled, or bypassed, during earlier mining were shipped to Moab. In 1977, over 27,000 tons of material was shipped which averaged only 0.08% U_3O_8.

In 1980 as the prices declined, so did the production at the

mine but the grade increased to over 0.10% U_3O_8. Energy Fuels Nuclear, Inc. began operating their White Mesa mill near Blanding, Utah in 1980 and some Enos Johnson ore was shipped there. Declining market prices forced the Enos Johnson Mine to close again in late 1982. The nearest market, Energy Fuels, near Blanding closed their White Mesa mill in February 1983.

During the period 1952 through 1982, the large underground mine on Enos Johnson's mining permit near Sanostee, produced about 135,600 tons of ore containing 326,900 pounds U_3O_8. This production ranks the Enos as the largest uranium mine in New Mexico, outside of the Grants mineral belt.

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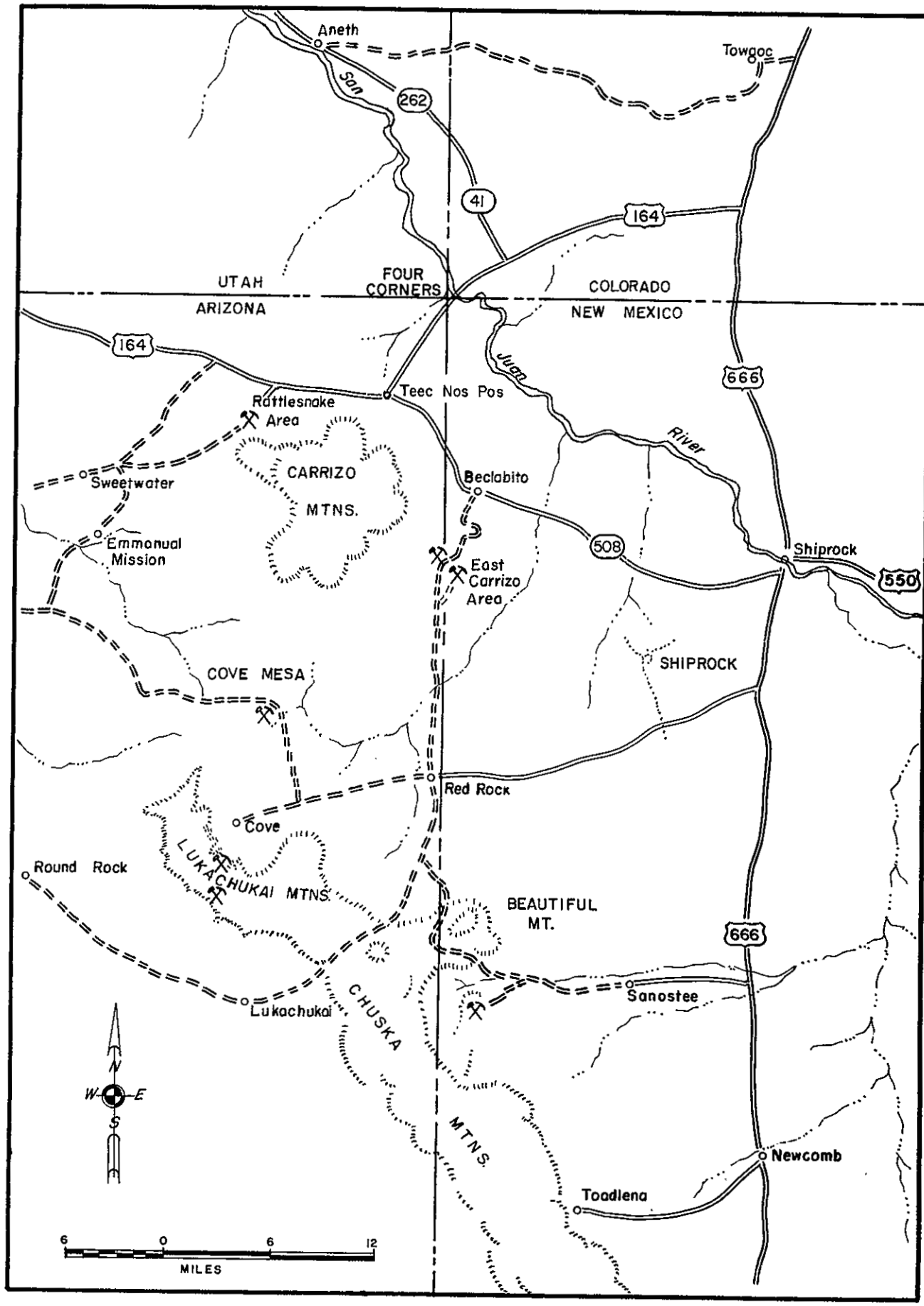

Figure 1. Index map of the Four Corners area showing the location of the principal uranium mines

Caption For Figure 2

Generalized geologic map of the Sanostee area showing the location of uranium mines and prospects. Modified after Blagbrough and others (1959). Land grid from Anderson (1981).

Properties with uranium production

1. Carl Yazzie 1
2. Castle Tsosie
3. Deneh Nezz 1
4. Deneh Nezz 2
5. Deneh Nezz 3
6. Enos Johnson
7. Enos Johnson 1
8. Enos Johnson 2
9. Enos Johnson 3
10. H.B. Roz 2
11. Horace Ben
12. Joe Ben 1
13. Joe Ben 3
14. John Joe 1
15. Key and Tohe
16. Reed Henderson (not shown, but located approximately one mile south-southwest of number 10)

Important prospects

A. Alfred Talk
B. David Kee
C. Joe Ben 2
D. John Joe 2
. Tyler

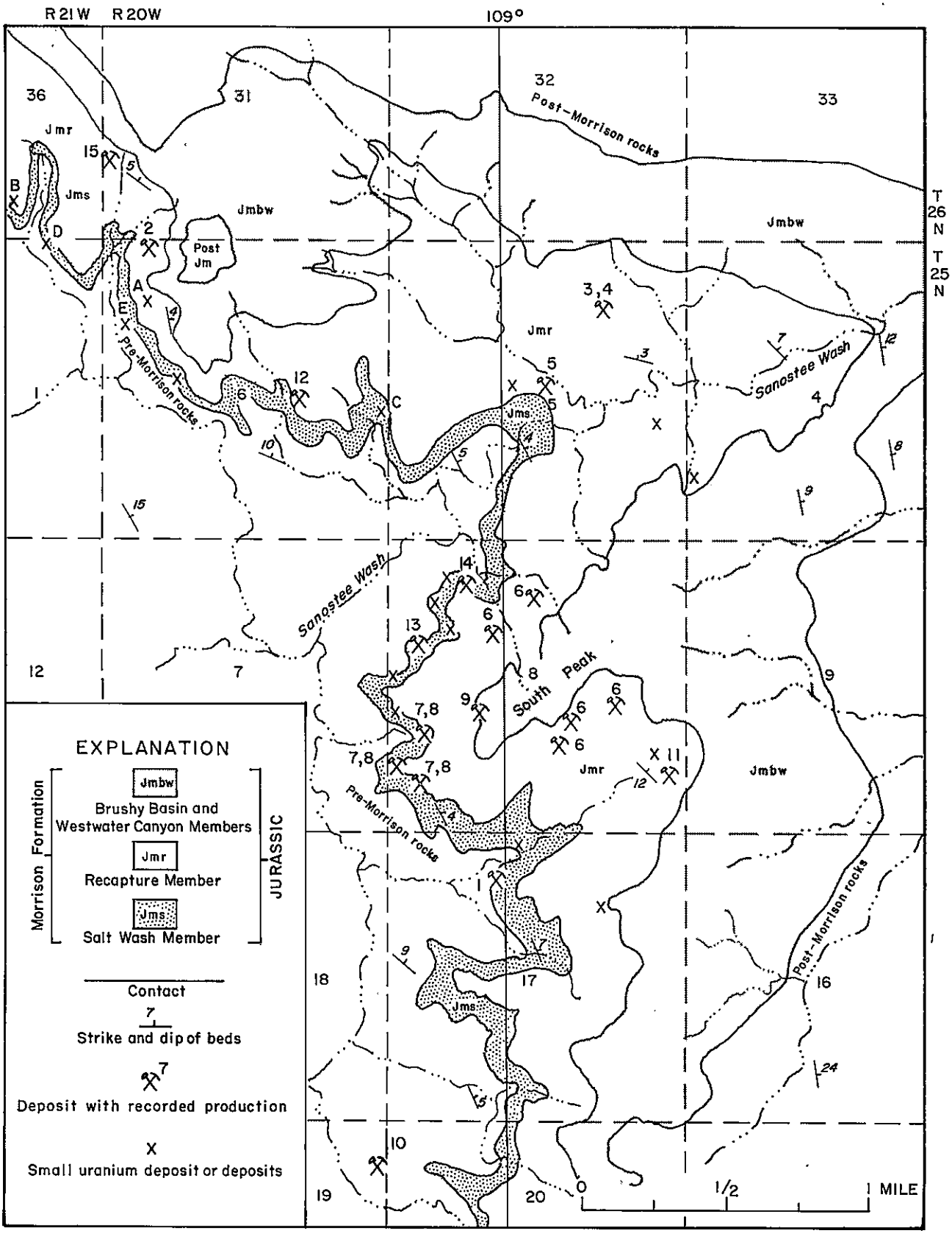
R 21 W
R 20 W
109°
T 26 N
T 25 N
Post-Morrison rocks
Pre-Morrison rocks
Sanostee Wash
South Peak
Jmr
Jms
Jmbw
Post Jm
A
B
C
D
E
EXPLANATION
Jmbw
Brushy Basin and Westwater Canyon Members
Jmr
Recapture Member
Jms
Salt Wash Member
Morrison Formation
JURASSIC
Contact
Strike and dip of beds
Deposit with recorded production
Small uranium deposit or deposits
0
1/2
1 MILE

Figure 2.

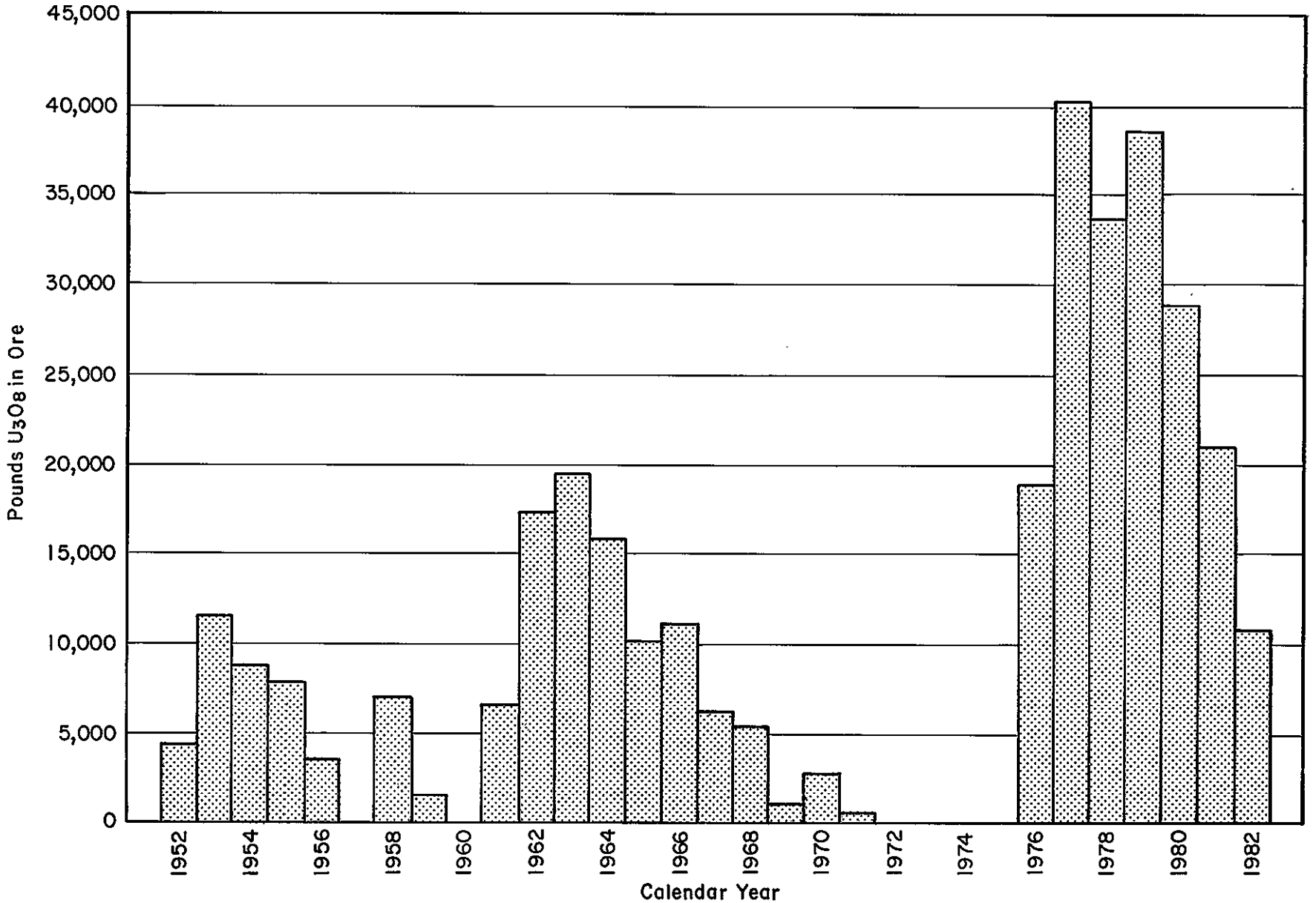

Figure 3. Uranium production Sanostee, San Juan County, New Mexico

TABLE 1
Details of Uranium/Vanadium Production, During the AEC
Procurement Program, at Sanostee, San Juan County, New Mexico

Index No.	Mine Name	Geologic Fm	Tons Ore	Pounds U_3O_8	% U_3O_8	Pounds V_2O_5	% V_2O_5	Periods of Production/ Operator(s)
1	Carl Yazzie 1	Jmsw	23	66	0.15	347	0.76	1954 - Bee-Shoshee Mining Co.
2	Castle Tsosie	Jmru	12	60	0.25	19	0.08	1956 - Bee-Shoshee Mining Co.
3	Deneh Nezz 1	Jmru	192[1/]	654	0.17	1,542	0.40	1952-55 - Rogers and Sons
4	Deneh Nezz 2	Jmru	113	327	0.14	700	0.31	1955 - Rogers and Sons
5	Deneh Nezz 3	Jmru	7	55	0.39	58	0.41	1955 - Rogers and Sons
6	Enos Johnson	Jmru	1,544	3,629	0.12	4,434	0.14	1952 - Enos Johnson Sr. 1952-54 - R. D. Young
7	Enos Johnson 1	Jmsw	133	265	0.10	343	0.13	1952-53, 1955 - R. D. Young
8	Enos Johnson 2	Jmsw	143	400	0.14	419	0.14	1952, 1954 - R. D. Young
9	Enos Johnson 3 (South Peak Mine) (Sanostee Mine)	Jmru	34,678	134,438	0.19	89,092[2/]	0.14	1952-56 - R. D. Young 1956 - Shiprock Uranium Corp. 1958-59 - Shiprock Industries, Inc. 1961-64 - A and B Mining Co. 1964-70 - Ray L. Williams
10	H. B. Roy 2	Jt	6	11	0.10	31	0.28	1954 - Bigler and Johnson
11	Horace Ben	Jmru	4	13	0.17	18	0.24	1952 - Cox and Rogers
12	Joe Ben 1	Jmru	6	42	0.36	49	0.42	1952 - Rogers and Sons
13	Joe Ben 3	Jmsw	219	884	0.20	3,207	0.73	1953, 1955 - Rogers and Sons

Index No.	Mine Name	Geologic Fm	Tons Ore	Pounds U_3O_8	% U_3O_8	Pounds V_2O_5	% V_2O_5	Periods of Production/ Operator(s)
14	John Joe 1	Jmsw	94	243	0.13	739	0.39	1955 - Rogers and Sons
15	Key and Tohe	Jmru	47	90	0.10	261	0.28	1954 - Bee-Shoshee Mining Co.
16	Reed Henderson	Jt	24	14	0.03 3/	52	0.11	1954 - Hancock and Hutchison

1/ Includes 115 tons containing 143 pounds U_3O_8 and 459 pounds V_2O_5, for which no payment was received.

2/ Vanadium oxide content reported for only 32,400 tons of ore.

3/ Due to the low grade, no payment was received for this shipment.

Geologic symbols - Jt, Todilto Limestone; Jmsw, Salt Wash Member, Morrison Formation; Jmrl, Recapture Member, Morrison Formation, lower unit; Jmru, Recapture Member, Morrison Formation, upper unit.

Compiled from ore receipts from buying stations and mills to the AEC.